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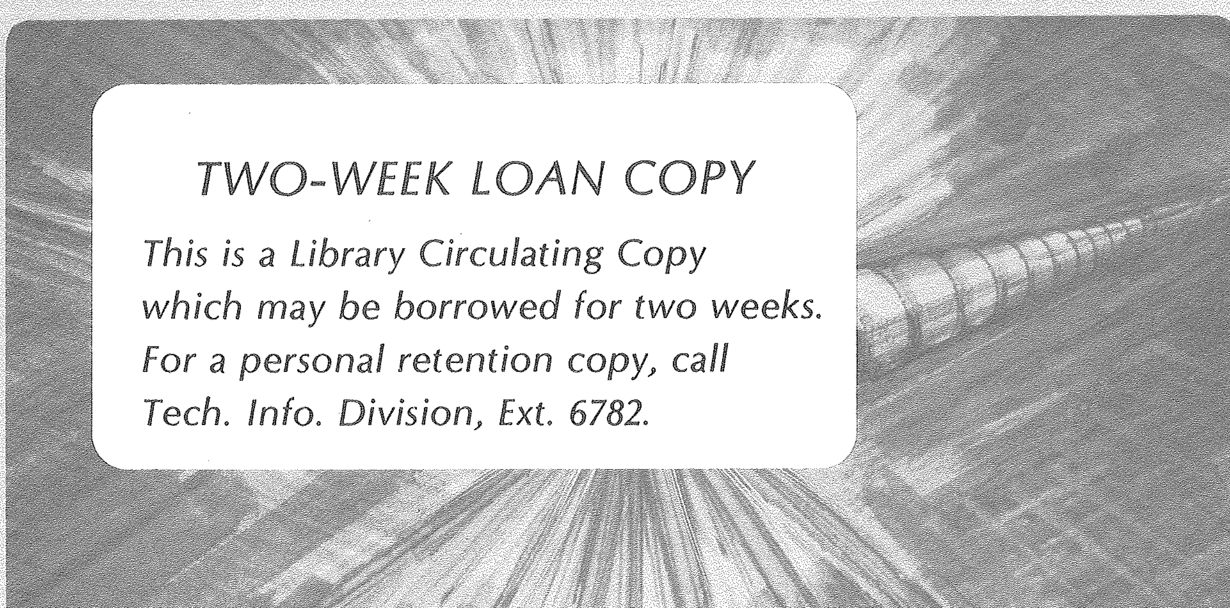

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ABSTRACT

A pulsed toroidal gas valve is described. The valve, which has a 10 centimeter aperture through the center, is designed to be used in toroidal plasma experiments where current-carrying conductors must pass through the axis of symmetry. The valve uses a coil and magnetic flux concentrator to displace an aluminum diaphragm by magnetic forces. Upon energizing the coil, the diaphragm opens in a few tens of microseconds and releases the gas (Hydrogen) contained in a toroidal plenum. The resulting gas distribution outside the valve contains up to 10^{19} H_2 molecules and has a high degree of toroidal symmetry.

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Introduction

A pulsed gas valve that opens in about 50 microseconds and produces a toroidally symmetric gas distribution is described here. The valve is designed with a 10 centimeter aperture through the center. This was done to allow axial current-carrying conductors to pass through the valve, a requirement of the plasma experiment using the valve. The opening mechanism consists of a thin disk of sheet aluminum (flapper) that is displaced by magnetic field forces. The field is produced and shaped by a coil and flux concentrator. The combination of low flapper mass and flux concentration makes for faster valve opening and lower driver energy than earlier designs.[1-3] The coil is driven by a 10 microfarad capacitor charged to 3 kilovolts switched on with an ignitron. The valve discharges up to 10^{19} H_2 molecules from a plenum in a single burst before the flapper closes. Measurements with a fast ion gauge show only slight azimuthal variation of gas density around the valve.

Principle of Operation

The displacement of the valve flapper by the coil and flux concentrator[4] is illustrated in Fig. 1. Magnetic field lines, generated by the current in the coil, are constrained to flow around the flux concentrator (split copper ring) and through the gap between the ring and flapper. The concentrated flux in this gap results in a large magnetic pressure[5] ($B^2/2\mu_o$ where B is the field in the gap (Tesla) and μ_o is the permeability of free space) against the flapper. The flapper, which is made as light as possible to minimize inertial effects is rapidly sprung out as shown in Fig. 1b. The application of the current and the deflection of the flapper must, of course, occur in a time scale short compared to the magnetic diffusion times of the components, to prevent the resistive dissipation of the magnetic field energy.

A rough estimate of the dynamics of the system is easily realized. When a current I flows in the coil, a flux ϕ links the coil where

$$\phi = LI,$$

and L is the inductance of the coil. If the coil is wound tightly against the split ring (flux concentrator) then all the flux ϕ is constrained to pass through the gap and the magnetic field is then given by the equation

$$B_{gap} \cong \frac{\phi}{2\Pi R_o(\delta + x)} \cong \left(\frac{LI}{2\Pi R_o(\delta + x)}\right) \text{ Webers/M}^2, \tag{2}$$

where x = the displacement from the initial position which results in a magnetic pressure on the flapper, P_{mag}, where

$$P_{mag} \cong \frac{1}{2\mu_o}\left(\frac{LI}{2\Pi R_o(\delta + x)}\right)^2 \text{ Nwt/M}^2 \tag{3}$$

The flapper is "sprung" into place with sufficient force to contain roughly one atmosphere of pressure in the plenum. If the driving current is made large enough so that P_{mag} greatly exceeds one atmosphere, then only the inertial term in the kinetic equation for the flapper need be retained, and

$$\rho_f \frac{d^2x}{dt^2} = P_{mag} = \frac{1}{2\mu_o}\left(\frac{LI}{2\Pi R_o(\delta + x)}\right)^2 \tag{4}$$

where ρ_f is the density of the flapper in kg/m^2. If δ is small compared to other dimensions and the current I increases linearly in time (as it does during the initial discharge of the capacitor, $(I = V_o t/L)$, then

$$x(t) \cong \left(\frac{9}{4}\right)^{1/3}\left(\frac{V_o^2}{2\mu_o \rho_f (2\Pi R_o)^2}\right)^{1/3} t^{4/3} \quad \text{Meters} \tag{5}$$

The time τ for the flapper to move a distance W is then given by

$$\tau \approx \left(\frac{8\mu_o \rho_f (2\Pi R_o)^2 W^3}{9V_o^2}\right)^{1/4} \quad \text{seconds} \tag{6}$$

Inserting typical numbers for the system at hand, and setting W equal to the minimum useful displacement of one mm in equation 6, τ is of the order of several microseconds. This is considerably faster than both the magnetic diffusion time of the aluminum flapper (estimated as several hundred microseconds) and the time for the gas to exit from the plenum (several tens of microseconds).

The above estimate for the opening time is very rough, and while not expected to accurately predict the valve performance, did serve as a useful guide in designing the valve.

Construction

A sectional drawing of the valve (Fig. 2) shows the valve as constructed and tested. The flux concentrator ring is made of copper and was filled with epoxy resin prior to being slotted radially. The slot, once cut, was also filled with epoxy and the o-ring groove (which must cross the slot) was machined out, along with the gas plenum region. The driving coil, which consists of 10 turns of heavy copper wire, was then wound around the outside and potted in a glass cloth-epoxy matrix. It has been found that uniformity in the winding of this coil is critical to good symmetry in the gas flow. In particular, stray fields where the coil leads leave the ring must be minimized. Care was taken to polish all the surfaces along the channel through which the gas escapes. A small diameter (3mm) copper tube connects the plenum to the gas supply.

The aluminum flapper which was originally used became permanently deformed after a few hundred shots causing the valve to leak. Several other materials were tried in place of aluminum, the most successful being a combination of aluminum with a second flapper behind it made of stainless steel, both .050 cm thick. The presence of the stainless steel did not noticeably affect the opening of the valve, and no deformation of the flapper has been observed in about 10^4 valve cycles.

Measurements

Initial tests of valve operation were done in a cylindrical vacuum chamber 60 centimeters in diameter by 120 centimeters long. The valve was mounted axially in the chamber and a nude ion gauge was supported in such a way that it could be rotated azimuthally around the valve, always at a constant radius from the valve axis. With this arrangement the toroidal symmetry of the gas pulse could be checked. During the first tests the azimuthal variation was quite large with almost no gas evolving from some places around the valve perimeter. Several remedies were tried unsuccessfully, and it was finally discovered that after many cycles the gas distribution became more uniform. After about 10^3 cycles the azimuthal variation was less than ten percent. It was found that this cycling was necessary every time the valve was disassembled, and it is speculated that stretching of the o-ring seal during assembly and resulting high and low spots was the source of the trouble. Repeated cycling may cause the seal to reseat itself more uniformly. It was found later that a teflon ring, machined to fit in the o-ring groove, worked much better. No cycling was required, and plus and minus fifteen percent uniformity of gas flow was achieved after the first few shots.

Next a series of ion gauge measurements were made with the azimuthal position fixed and the radius of the gauge varied. Shown in Fig. 4 are oscilloscope traces of the gas density versus time at radii of 2.5, 5.0 and 7.5 centimeters from the exit of the valve (note the different vertical scales in the pictures). The gauge was uncalibrated for these shots, the electron emission current being kept very low to avoid space charge saturation of the tube*. The total gas output of the valve was monitored with another (calibrated) tube which measured the net pressure jump in the vessel after a shot. Knowing the volume of the tank, the total number of gas molecules injected into the system was calculated. This measurement indicated that about 35% of the gas in the plenum was emptied during a shot.

Once properly cycled the valve is extremely repeatable in its operation. It has since been successfully incorporated into a plasma gun experiment where it has operated without failure for many thousands of shots in a year of operation.

* The tube used was a standard Veeco VG-1A ionization gauge with the glass envelope cut away. The ion collector (ground potential) was connected to the oscilloscope through a short length of cable with a 1 megohm resistor to ground.

REFERENCES

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2.) J. Marshall, Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy (United Nations, Geneva, 1958) Vol. 31, 341.

3.) B. Gorowitz, K. Moses and P. Gloersen, Rev. Sci. Inst., 31,146.

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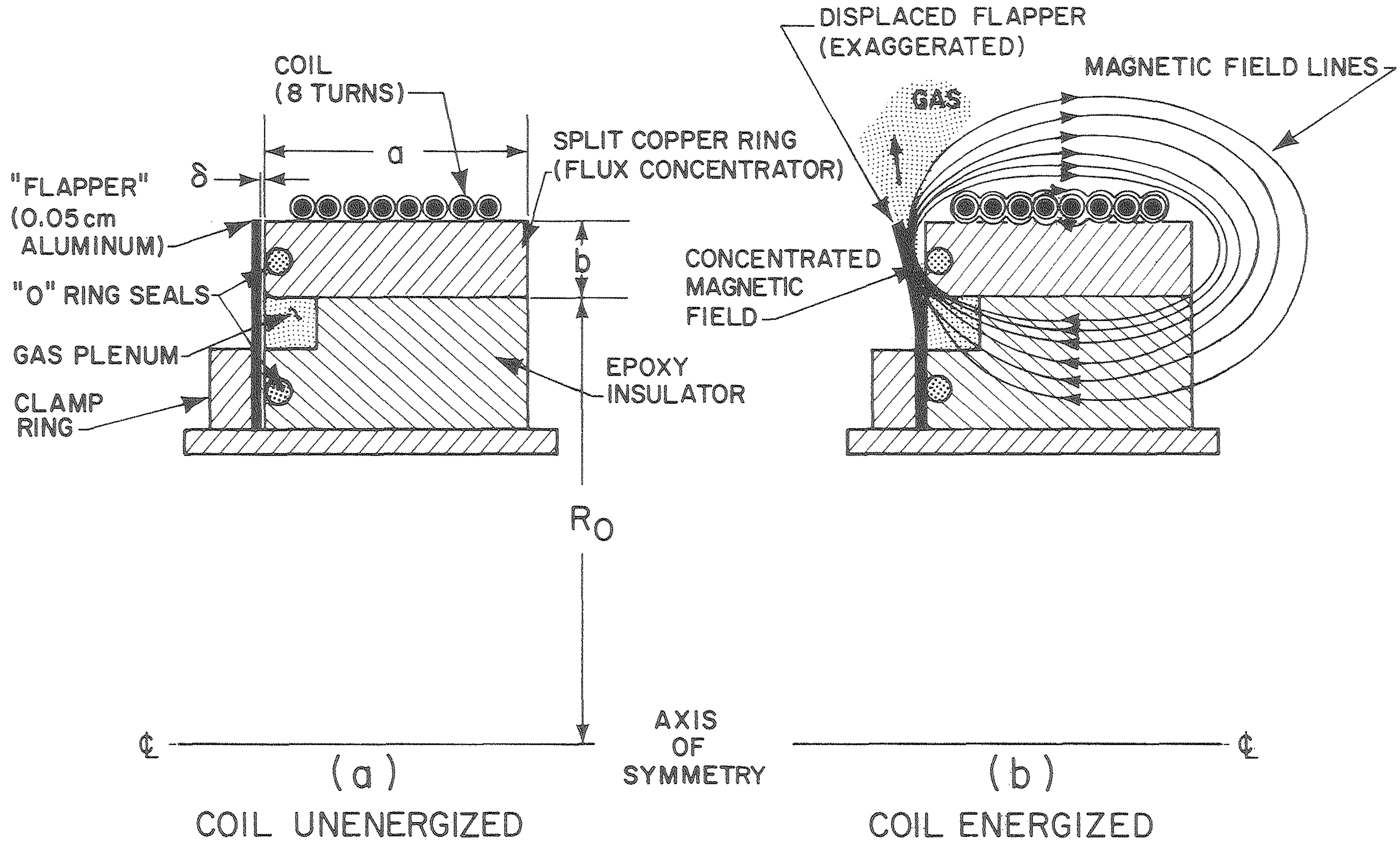
FIGURE CAPTIONS

FIGURE 1. Artists sketch of valve illustrating the dynamics of opening.

FIGURE 2. Cross sectional view of valve.

FIGURE 3. Oscilloscope record from nude ion gauge.



XBL 7911-5091

Fig. 1

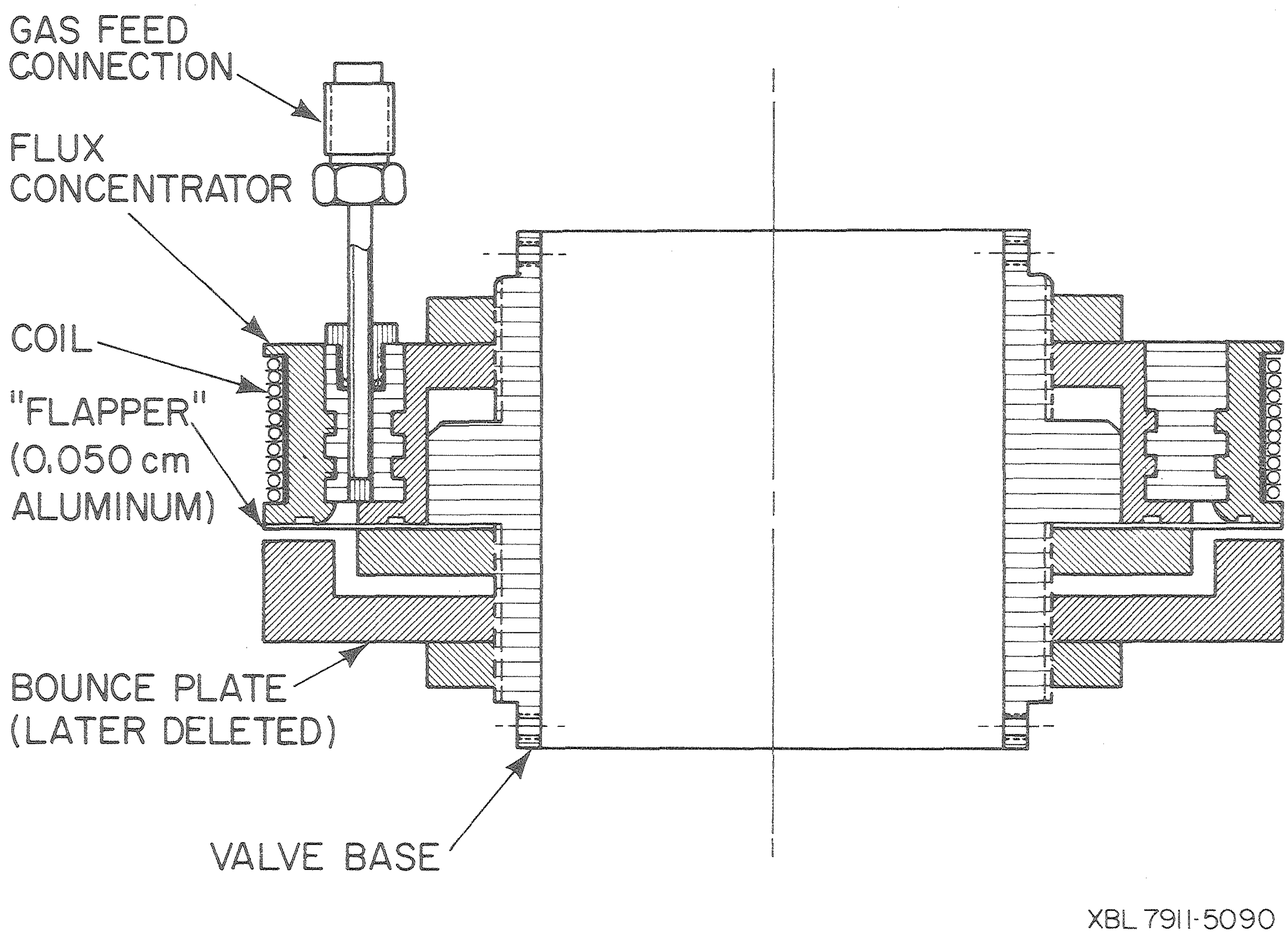
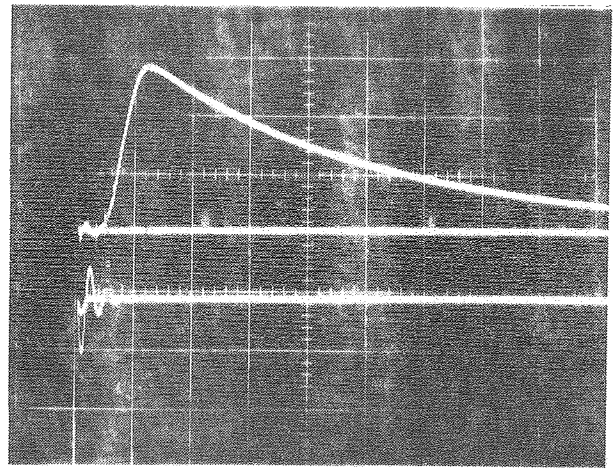

GAS FEED
CONNECTION
FLUX
CONCENTRATOR
COIL
"FLAPPER"
(0.050 cm
ALUMINUM)
BOUNCE PLATE
(LATER DELETED)
VALVE BASE
XBL 7911-5090

Fig. 2

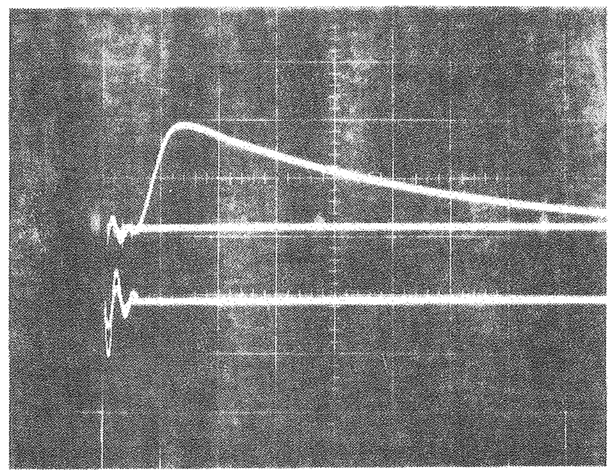
(a)

Gauge 2.5 cm from valve
Top trace; gauge, 2 volts/cm
Bottom trace; coil current
3 kA/cm



(b)

Gauge 5.0 cm from valve
Top trace; gauge, 0.5 volts/cm
Bottom trace; coil current
3 kA/cm



(c)

Gauge 7.5 cm from valve
Top trace; gauge, 0.1 volts/cm
Bottom trace; coil current
3 kA/cm

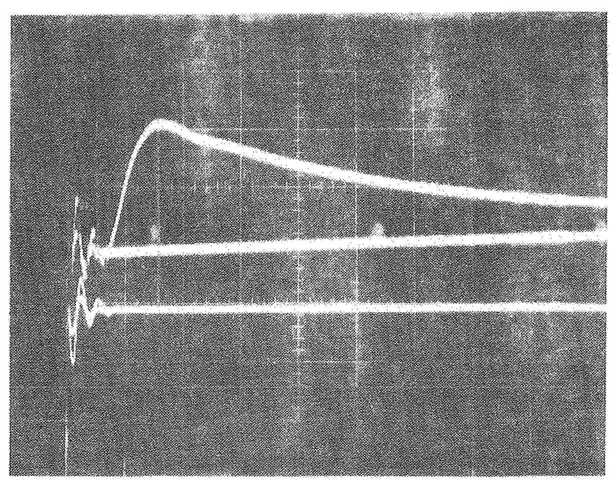


Fig. 3

Sweep: 200 μsec/cm

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